ЭКСПЕРИМЕНТАЛЬНЫЕ И ЭМПИРИЧЕСКИЕ ИССЛЕДОВАНИЯ

Overload but guide: The impact of environment saturation on attention and working memory under real and digital conditions

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The digital environment surrounds us everywhere. However, little is known about the differences between digital and real environmental impact on cognitive functions. Initially, the present study aimed to juxtapose attention and working memory (WM) performance under digital and real conditions. In Experiment 1, attention and WM were assessed using modified versions of classical tasks presented in either a digital (computer-based) or real (paper-based) format. The results showed that both sustained attention and visual WM were superior in the real environment, suggesting a potential overloading effect of the digital context. Experiment 2 examined the mechanisms underlying attentional shifting and sustained attention in digital environments by manipulating the level of environmental saturation (SAT). SAT refers to the degree of interactivity in an environment, particularly in terms of whether actions are initiated and guided by the human user or by the system (e.g., interface elements). A specific manipulation involved perceptual feedback – such as hover effects (changes in element state or color in response to user actions). The results indicated that sustained attention performance improved in highly saturated digital environments, whereas this effect was not observed for attentional shifting. These findings suggest that, although digital environments may overload attentional resources compared to real ones, certain features of saturation—such as interactive feedback – can enhance attentional engagement. Thus, environmental saturation plays a guiding role in shaping cognitive performance in digital contexts.

Keywords: digital vs. real environment, cognitive-digital interaction, working memory, attention, hover effect, overload, guidance

Introduction

Nowadays, life is unthinkable without digital tools such as computers, smartphones, tablets, etc. Then, such dense interaction with the digital environment raises the question of its potential impact on cognitive functions. Generally, people perceive the digital environment's impact as negative and overwhelming [Firth et al., 2019; Wilmer et al., 2017]. A consistent question in response to such a thesis is "compared to what are the impacts of the digital environment seen as negative?" Then, reviewing studies comparing cognitive performance in real vs. digital environments can shed light on the question. However, it should be noted that despite the available evidence of differences in cognitive performance in environments, there is no single theoretical line that would explain the mechanisms underlying the observed phenomena. A possible explanation for this state of affairs is the lack of development of theoretical models in the field of cognitive-digital interaction (CDI). To address this gap, the present study aims to present a theoretical model followed by empirical validation.

Literature review

Comparison of cognition in real vs digital environment

Research suggests that the task presentation environment can influence memorisation processes [real objects are remembered better compared to their photo or computer image; Snow et al., 2014] as well as affordance perception [real objects cause greater interference compared to on-screen presentation in the Flanker task; Gomez et al., 2017; Sztybel et al., 2019]. Scholars highlight that the AI algorithms within the digital systems, along with the organisation of interface elements, can influence the processing, storage, and operation of information by the cognitive system [e.g. Marsh & Rajaram, 2019; Firth et al., 2019]. The prevailing number of studies in the field of environmental comparison focus on the study of reading or writing, i.e., complex processes. The main result of such studies is the superiority of using the real over the digital environment in terms of remembering and comprehending information when it is read or written on paper [e.g., Sherbakova & Isaeva, 2024; Bouriga & Olive, 2021]. However, some studies do not find differences in the above parameters [e.g., Ardislamov et al., 2023]. One possible way to find explanations is to examine environmental influences on cognitive functions as mechanisms underlying these complex processes.

Only a small number of studies, in comparison to the previously mentioned field, are concerned with exploring regularities of cognitive functions when interacting with the digital environment. For example, the study by Umejima et al. [2021] investigated recognition using tablets, smartphones, and notebooks. As a task, they used Schedule-recording task — subjects had to read to a dialogue and write out an indication of their upcoming plans on a calendar (day, time, type of activity). They then listened to an audiobook (which they would later be asked about) and took a retrieval test on the dialogues. Participants were presented with a multiple-choice question on a screen. The whole procedure took place in the fMRI scanner. The time of information input was recorded, as well as the accuracy of the retrieval test. The results showed that the group performing the task on paper was faster and more accurate. Differences were also found in the level of activation in different parts of the brain related to memory, visual imagery, and language. The authors attribute the differences obtained to the fact that the paper allows for more "rich" information (spatial and structural), which is used as a kind of cue in the retrieval phase. Nevertheless, the authors do not describe in detail the mechanisms underlying the system of cues. In addition, a study by Wiechmann et al. [2022] found no differences between tablet, laptop, and paper conditions when listening to a video lecture and taking notes on it.

Nevertheless, the work of Umejima et al. [2021] is consistent with the results of Lin and colleagues [2015]. They used short-term memory and visuospatial ability tests embodied on paper and presented on a tablet. As a result, they found superiority in performing these tasks on paper. The researchers attributed these findings to the higher refresh rate of digital media, which can lead to quicker eye fatigue. Additionally, they highlighted the necessity of interface navigation in the case of tablet usage, which is considered a resource consumption factor. Thus, the explanations of the two papers point to differences specifically in the visual modality and spatiality of the two environments. However, unlike Umejima et al. [2021], Lin and colleagues [2015] suggest that these features have an effect on resource allocation. In general, the reviewed works do not use or propose a model of environmental differences. Their explanations are ad hoc in nature. The lack of theoretical elaboration within the framework of environmental influence research may underlie the non-systematic and often exclusively exploratory nature of works in this direction.

Theoretical models

Few environment models include the work of Kallinikos et al. [2013], who suggest that digital environments can be described using the concepts of editability, reprogrammability, distributedness, and interactivity. The authors suggest that the digital environment has more capabilities, which distinguishes it from the real world. This is expressed in the characteristic of interactivity. The other characteristics are not discussed in the context of comparing environments. Moreover, this model does not make any claims about the influence of characteristics on mental reality. In this regard, Huang's [2003] model is more relevant. It describes the digital environment through the characteristics of complexity, novelty, and interactivity. Together they influence the sense of satisfaction in using the environment. A private provision is that complexity has an effect on attention. Complexity is understood as the abundance and variety of information. A high level of complexity can lead to attention overload and increased dissatisfaction. Huang cites survey results as an empirical test of this assertion [Huang, 2003]. Indeed, Wang et al. [2014] showed in an eye-tracker experiment that attention does become more distracted as site complexity increases (increasing number of fixations), but this is only true at low cognitive load. However, Huang's model describes environmental influences at the metacognitive level, which makes it difficult to apply it to describe and explain the effects obtained in the works discussed above.

Due to the lack of theoretical models of the interaction of cognitive functions with real and digital environments, we introduce our own. Our model considers the interaction of environments with first-order (object-level) cognitive processes according to Nelson's model [1990] — attention, memory, and mental operations of thinking. We propose our own environmental characteristics: saturation (SAT) and degrees of freedom (DF). SAT of the environment is the degree of its interactivity, i.e., who/what can initiate an action and monitor its performance. This characteristic affects attention —selection, maintenance, allocation, and monitoring. DF of the environment is the possibility of realising an action and who/what performs it. Functions and strategies of encoding, storing, and manipulating information (memory and thinking operations) are associated with DFs. SAT of the digital environment can draw attention to its DF to realise functions that correspond to the notion of signifier [Norman, 2008]. For the purposes of this paper, we focus on SAT, so we will present the main points about this characteristic in two environments.

In a digital environment, there are the following aspects of SAT: perceptual feedback from interface elements (changes in state or colour during interaction), notifications, and banners. Therefore, exogenous factors (SAT aspects) can influence attention by capturing or redirecting it. At the same time, the real environment (paper) does not have these aspects. This means that processing is associated mostly with the endogenous attention mechanisms. Thus, the need to constantly filter and inhibit external factors leads to poorer attention performance in digital environments. However, according to activity-centered design (ACD) [Williams, 2009], the essence of interface interactivity is in the guiding effect — helping the user achieve the goal of the activity. Therefore, SAT, as signifiers in the digital environment, directs or allocates attention towards functional elements, thus making it easier to navigate. Therefore, the high SAT of the digital environment can be considered not only as an overload but also as a cue that guides attention. High SAT refers to the presence of all three highlighted aspects: perceptual feedback, notifications, banners. Undoubtedly, these aspects are present only in the digital environment and fit the definition of interaction initiation on its part. However, visual perceptual characteristics such as distinctiveness of colour, shape or arrangement of individual elements or presentation of information can be considered as part of SAT because they are exogenous and can attract attention despite the lack of interaction as outcomes of the system at the moment of human interaction with it. Within this broader view, the real environment also has SAT — the presence of exogenous factors that can redirect attention. However, this type of environment does not contain exactly interactive elements. Therefore, we can say that the real environment has a low degree of SAT compared to the digital environment. For example, on both paper and screen, highlighting text in red will attract attention exogenously. However, in a digital environment, when interacting with a red element (cursor direction, clicking) there can be a change in its colour or state, which denotes the interactivity of the element — the ability to edit it, open another link, a drop-down menu. Moreover, even without directly clicking on this red element, it may start to move or change colour to attract attention and prompt interaction and implementation of the function. In a real environment, the red highlighting would be permanent (not editable), would not realise any function. This makes the real environment seem more stable and easier to inhibit information.

Summary

There are two issues in the CDI area. First, the lack of empirical work aimed at comparing cognitive functions in the two types of environments. In particular, little work has examined auditory WM or attention. Furthermore, there is a dearth of theoretical models that describe the characteristics of both digital and real environments. Thus, the first experiment of the present work aims to investigate the effects of environment (real vs. digital) on visual-spatial and auditory WM and attentional sustainability and shifting using modifications of classical tests and an ecologically valid task. Also, since there is a dichotomy ("overloading vs. guidance") about the nature of the influence of the digital environment, it was decided to conduct Experiment 2. It is aimed at clarifying the influence of the SAT of the digital environment on attention. The proposed model of environmental influences will be used to describe and explain the results obtained.

Current study

Experiment 1

The present study was devoted to comparing attention and WM in digital and real environments. To examine these constructs, it is common to use specially developed methods, such as N-back, Go/No-Go tasks, and so on. However, all of them are designed and administered on a computer, so they cannot be converted to paper format. Additionally, the practice of research aimed at the influence of environments is based on presenting participants with tasks (activities), which in ordinary life can be realized both on a computer and on paper. Taking into account all the above, we decided to modify the traditional methods and present them in a context resembling the activities of everyday life — organizer usage. The use of organizers was motivated by the fact that there are both paper and computer versions of this form of activity. Consequently, it is possible to present the methods not just in digital or printed form but in context.

Baddeley's model was taken as the basis for the WM tasks. This model distinguishes between a visuospatial sketchpad and a phonological loop [Baddeley, 2012]. The visuospatial sketchpad task in the current study utilizes elements of classical visual WM tasks: retention of information about the mutual location of objects (Matrix span and symmetry matrix task) and matching information about the spatial location of objects with new information from a list (Operation span task). The phonological loop task uses auditory loading with different lengths of each element (items) and different numbers of them (Word List Recall task, Reading span task). Thus, our WM tasks resemble Schedule-recording task from Umejima et al. [2021] study.

The main scaffold for attention methods was the Bourdon test [Nasiri et al., 2023]. This method relies on holding several objects (letters, numbers, words, and symbols) in WM and sequentially searching for the corresponding stimuli among distractors over a period of time. All stimuli are organized into rows and columns. This method traditionally measures sustained attention, which we will hereafter refer to as attentional sustainability. The study of attentional shifting is characterized by a change in the search target. Using the principles of the Bourdon test, we added switching between items held in WM to the instruction and procedure (the Attentional shifting task).

The description of each task is provided below.

Phonological loop task

Participants were audibly presented with phrases indicating day and event (a two-element condition) and day, event, and time (a three-element condition). For instance, "Monday – Meeting" and "Monday – Meeting – at 11 a.m.". After listening, the task was to fill slots in the organiser according to the content of the audio recording (Figure 1. A). There were four levels of load depending on the number of phrases for holding: 2, 3, 4, and 5. The trial lasted only two minutes. The task lasted about 18 minutes and contained 8 trials (4 for each condition).

Visuospatial sketchpad task

Participants were shown a screen of organizers for 5 seconds with the slots (rectangles). It might be 2, 3, 4, or 5 slots on the screen — levels of load (Figure 1. B). Then, they were presented with a to-do list. Their task was to write out as many "to-do" items from the list as possible in 2 minutes, so the items would not overlap with the slots they had already seen on the screen before. The task lasted about 12 minutes and consisted of 4 trials.

Modified Bourdon test

Three words denoting events (for example, "training, meeting, shopping") were presented for 5 seconds. Participants had to memorize them, then find and cross out all target words contained in slots (green rectangles) (Figure 1. C). Each trial lasted only two minutes. The task lasted about 12 minutes and contained 6 trials.

Attentional shifting task

For 5 seconds, participants were presented with two combinations of the day and event. For example, “Monday – training, Sunday – shopping”. The task was to search for events on a certain day and cross them out. Furthermore, the subject had to change the target (the combination) that was being searched for on command from the experimenter every 15 seconds. The total time for a trial was 2 minutes. The task lasted about 12 minutes and contained 6 trials.

Pilot study

To test the elaborated tasks, the pilot study was conducted. Based on previous studies and our model of environmental influences, attention and WM should be better in the real environment. Paper represented the real environment, whereas a computer — the digital one. Participants in the computer group executed the task on the Google calendar website, whereas in the paper group dealt with the printed version of this website (Figure 1).

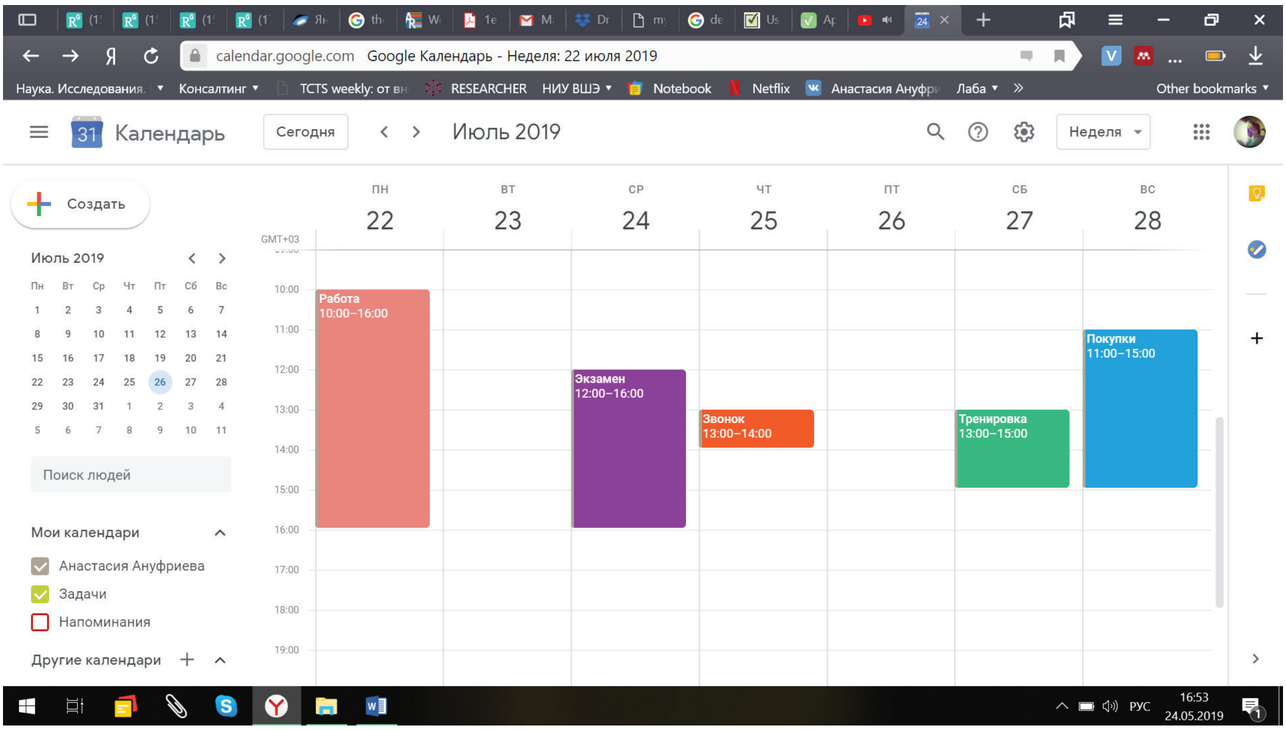
Equipment

The computer condition was made on an ASUS ZenBook UX305 computer with a screen resolution of 13.3 (3200×1800). The real condition was made on paper, size A4 (210×297 mm). The Bandicam programme for the computer version and the Go-Pro Hero camera for the paper version were used to record the experiment. Later, the records were used to compare the time with the stopwatch data, which was used to directly record the time during the experiment.

Pilot results

22 participants (11 per group) were recruited to test tasks and procedures. A Mann-Whitney U-test was conducted for comparison. The phonological loop task showed the following results: in the condition of presenting audio recordings “day of the week – type of activity”, no significant differences were found between the groups (for all $p > .05$). However, in the conditions of presentation “day of the week – type of activity – time”, significant differences were found in the time of task completion ($p < .03$). No significant differences in accuracy were found in the Visuospatial Sketchpad task ($p > .09$), but significant differences in the number of completed items were obtained ($p < .01$). In the Attentional shifting task, significant differences between groups were observed only in time ($p < .02$). The only task that showed significant differences in all compared parameters was the Modified Bourdon test. In this task, the number of correctly detected slots ($p < .02$), the number of not-found slots ($p < .02$), and the time ($p < .01$) significantly differed between the computer and paper groups. However, there were no significant differences in the number of false alarms ($p > .05$). Wherever differences were found, the paper group was better; they were more accurate and faster.

Based on the pilot conducted, it was decided to make the following changes. First and foremost, the trial time was reduced to 1 minute for the main study. It was assumed that during the 2-minute trial, participants



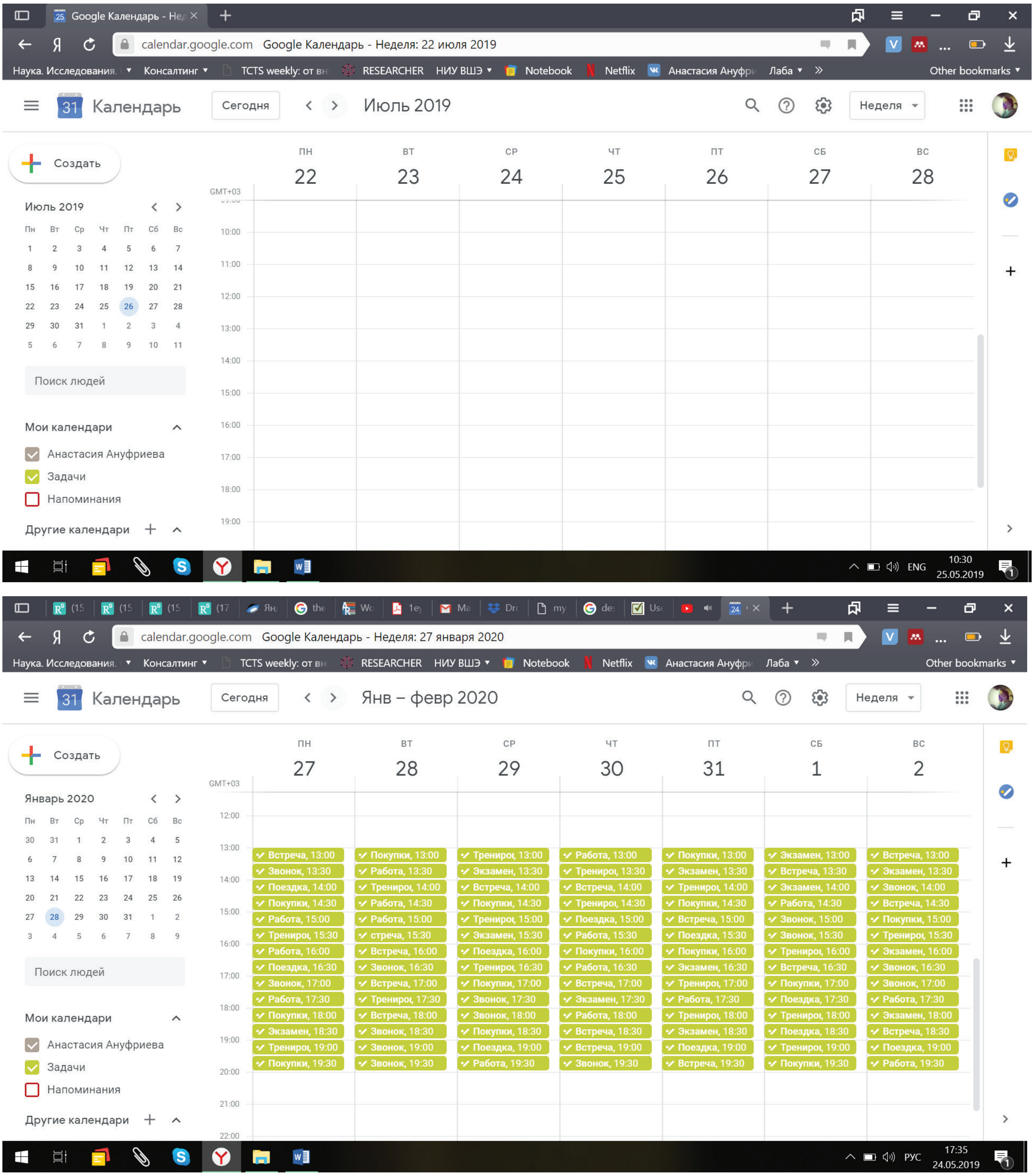


Figure 1. The appearance of the task space in the pilot and main experiments

Notes. A. A task space for the Phonological loop task and the Visuospatial sketchpad task. B. An example of stimulus in the Visuospatial Sketchpad task. C. A task space for the Modified Bourdon test and the Attentional shifting task.

had a chance to revise their answers, which could lead to a lack of differences between conditions in the pilot study. According to a number of studies [Donkin et al., 2014; Li et al., 2023; Wu et al., 2022], in situations of time pressure, the indicators of cognitive processes change as well as the text comprehension score [Delgado & Salmeron, 2021; Porion et al., 2016]. Secondly, in the Phonological loop task, the trials with only three elements ("Monday – Meeting – at 11 a.m.") of the phrase were left, as no differences were observed for two-element conditions. Also, the level of load with two phrases or slots was removed from analysis for both the Phonological loop and the Visuospatial sketchpad tasks. They were presented to participants as training trials in Main Experiment. Furthermore, the classic Bourdon test (paper version) and the N-back task were added to control the equality of attentional and WM spans between groups.

Main Experiment

This experiment's hypothesis was equivalent to the pilot study.

Sample

Based on the analysis of studies from the literature, the average sample size is 55 individuals. On average, the effect size f was 0.81 with 0.01 or less alpha, and the achieved power was 95 % for accuracy in memory tests. Relying on these data, we conducted a sample size analysis using the G*Power 3.1.9.4 programme. According to its results, the total sample size should have been 31 people. Based on all this information, we decided to collect at least 30 people per group.

65 volunteers aged from 18 to 28 years ($M = 21.5$, $SD = 2.3$, 37 female, 30 real group, 35 digital group) with normal or corrected-to-normal visual acuity, without neurological disorders, were invited to participate for a course credit. All participants provided written, informed consent. The study was approved by the local ethics committee.

The subjects were assigned to one of two groups: the digital (computer) or the real (paper) group. Before the experiment, each subject took a survey in Google Forms to determine their experience with using the organizer. They were asked whether they use organizers (calendars). If yes, which type (digital or real) do they prefer? The distribution of answers was as follows. In the computer group, 8 participants had no experience, 11 preferred digital organizers, 8 — real organizers, and 8 preferred both. In the paper group, 7 participants had no experience; 7 preferred digital organizers, 8 — real organizers, and 8 preferred both.

Equipment

The technical equipment was equal to the pilot experiment**.**

Design

There was one between-subject independent variable: type of environment (paper or computer). Operationalisation and appearance are as described in the Pilot Study. In the Phonological loop task and the Visual sketchpad task, levels of load were varied. There were three levels in the Phonological loop task, depending on the number of phrases that participants were presented with: 3, 4, and 5. For the Visual Sketchpad task, the number of slots on the screen that had to be held varied: 3, 4, and 5. In the Modified Bourdon test and the Attentional shifting task, participants always had to memorize three words or combinations for further searching.

For all tasks, the execution rate was measured as a total number of clicks, cross-outs, or written-out items per second (total number of processed items divided by trial duration). The following comparisons were made. For the Phonological loop task and the Visual sketchpad task, accuracy is correctly written-out items, mistakes are wrongly written-out items, and the total number of written-out items. Additionally, we understood mistakes in the Visual Sketchpad task as intersections between items from the list and the previously seen organizer screen. For the Modified Bourdon test and the Attentional shifting task, a number of correctly detected slots (CD), false alarms (FA), and omissions (OM) were measured.

Procedure

The experiment was conducted in a laboratory room where only the experimenter and the subject were. The subjects were instructed to leave their gadgets in silent mode and put them away in their bags. The experimenter informed the subject that there would be camera or screen recording. In the beginning of the experiment, all participants passed the N-back task (to control the equality of WM capacity between groups) and the classic Bourdon test on paper (to control the equality of attention capacity between groups). In the main part of the experiment, participants were presented with four tasks in a randomised order. For each task, an instruction was prepared on the screen (computer group) or on the paper (paper group).

Results

Data analysis and visualisation were performed in the software environment R v. 1.2.1335. The Mann-Whitney test showed no significant differences between the groups for N-back tasks, $W = 56.5$, $p = .61$, $r = .76$. The classical Bourdon test as a method to control equality of attention capacity between groups also showed no significant differences between the groups, $W = 53.5$, $p = .54$, $r = .77$. In addition, covariance analysis revealed that "subject's experience" did not affect the results ($p > .05$).

Phonological loop task

The test of homogeneity of variance (Levene's test) showed equality of variance between groups on all dependent variables for the Phonological loop task (all $p > .57$). All data are presented with sphericity corrections. Pairwise comparisons are performed with Bonferroni-Holm adjustment method. According to a two-way mixed ANOVA, where group was the between-group factor and level (number of items) was the within-group factor, no effect of the group factor was found on the number of written-out items, $F(1, 63) = 2.38$, $p > .12$, $\eta_p^2 = .02$ or interaction between factors, $F(2, 126) = 0.41$, $p > .67$, $\eta_p^2 = .001$. The impact of level was found, $F(2, 126) = 6.26$, $p < .01$, $\eta_p^2 = .02$. RM ANOVA showed that the level factor had no significant influence on the number of written-out items for the computer group, $F(2, 68) = 1.80$, $p > .36$, $\eta_p^2 = .03$. However, an influence of level was found for this parameter in the paper group, $F(2, 58) = 5.12$, $p < .01$, $\eta_p^2 = .18$. Pairwise comparisons showed differences between levels 3 and 4 in the paper group ($p <$,01). Thus, at loading level 3, the average number of words written-out was 2.9 (SD = 0.31), while at level 4, it was 3.4 (SD = 0.56).

A two-way mixed ANOVA demonstrated no significant effect of group, $F(1, 63) = 2.93$, $p > .09$, $\eta_p^2 = .02$ and level, $F(2, 126) = 2.02$, $p > .14$, $\eta_p^2 = .02$ on the correctly written-out items. But a significant interaction of factors, $F(2, 126) = 3.39$, $p < .04$, $\eta_p^2 = .03$ was found. RM ANOVA showed the effect of level in the computer group, $F(2, 68) = 5.69$, $p < .01$, $\eta_p^2 = .17$ but not in the paper group, $F(2, 58) = 0.62$, $p > .54$, $\eta_p^2 = .01$. Pairwise comparisons in the computer group showed differences between correctness at 3 (M = 1.74, SD = 0.88) and 5 (M = 1.15, SD = 0.93) loading levels ($p < .01$).

The analysis of the number of mistakes showed no influence of the group, $F(1, 63) = 0.48$, $p > .54$, $\eta_p^2 = .001$, or interaction of factors, $F(2, 126) = 1.85$, $p > .16$, $\eta_p^2 = .02$. The influence of the level was found, $F(2, 126) = 9.21$, $p < .001$, $\eta_p^2 = .16$. RM ANOVA for the paper group showed no effect of level on the number of mistakes, $F(2, 58) = 3.31$, $p > .05$, $\eta_p^2 = .05$. The influence of level on this parameter in the digital group was found, $F(2, 68) = 7.55$, $p < .001$, $\eta_p^2 = .11$. Pairwise comparisons showed differences between levels 3 (M = 1.17, SD = 0.85) and 4 (M = 1.74, SD = 1.16), $p < .02$, 3 (M = 1.17, SD = 0.85) and 5 (M = 2.17, SD = 1.43), $p < .02$. There were no differences between groups in execution rate, $F(1, 63) = 2.38$, $p > .13$, $\eta_p^2 = .02$.

Thus, for the Phonological loop task, no differences were found between groups for any of the parameters, but there was an increase in mistakes depending on

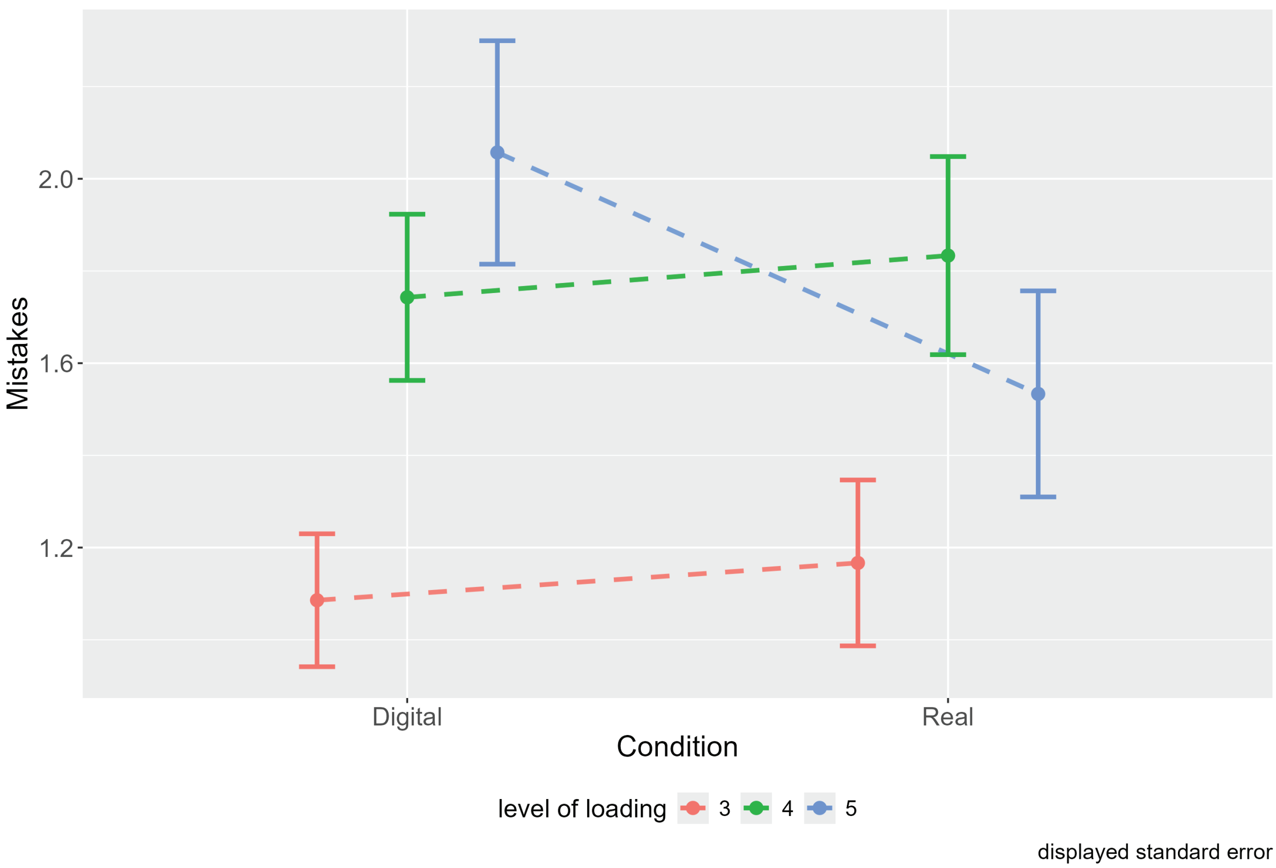


Figure 2. *Result for Phonological loop task (number of mistakes) in Experiment 1*

the level of load in the computer group (Figure 2).

Visuospatial sketchpad task

The test of homogeneity of variance (Levene's test) showed equality of variance between groups on all dependent variables for the Visual sketchpad task (all $p > .16$). All data are presented with sphericity corrections. The effects of group factor, $F(1, 63) = 47.03$, $p < .001$, $\eta_p^2 = .32$, and level, $F(2, 126) = 4.83$, $p < .001$, $\eta_p^2 = .03$, on the number of written-out items were found. The paper group wrote out more words than the computer group (Figure 3. However, there was no significant factor interaction, $F(2, 126) = 0.18$, $p > .09$, $\eta_p^2 = .001$. According to RM ANOVA, the influence of level was not within both groups: the computer group, $F(2, 68) = 3.29$, $p > .05$, $\eta_p^2 = .04$, the paper group, $F(2, 58) = 1.68$, $p > .29$, $\eta_p^2 = .02$. The influence of group, $F(1, 63) = 53.13$, $p < .001$, $\eta_p^2 = .35$, and level, $F(2, 126) = 8.11$, $p < .001$, $\eta_p^2 = .04$, was found for the correctness of written-out items. The correctness of the written-out words was higher in the paper group than in the computer group (Figure 3). There was no significant interaction, $F(2, 126) = 0.03$, $p > .19$, $\eta_p^2 = .001$. RM-ANOVA showed no influence of level in the paper group, $F(2, 58) = 2.77$, $p > .07$, $\eta_p^2 = .04$, but an influence was found in the computer group, $F(2, 68) = 5.84$, $p < .01$, $\eta_p^2 = .15$. Pairwise comparisons demonstrated differences between levels 3 ($M = 3.55$, $SD = 1.80$) and 4 ($M = 2.62$, $SD = 1.67$), $p < .01$, 3 ($M = 3.55$, $SD = 1.80$) and 5 ($M = 2.8$, $SD = 1.78$), $p < .02$.

Two-way mixed ANOVA, where group was the between-group factor and level (number of slots) was the within-group factor, showed no effect of group, $F(1, 63) = 1.25$, $p > .38$, $\eta_p^2 = .02$, and level, $F(2, 126) = 1.62$, $p > .21$, $\eta_p^2 = .01$, and no interaction of factors, $F(2, 126) = 1.12$, $p > .88$, $\eta_p^2 = .001$, on mistakes as wrong written-out items There was also no effect of group, $F(1, 63) = 0.05$, $p > .83$, $\eta_p^2 = .001$, level, $F(2, 126) = 0.68$, $p > .56$, $\eta_p^2 = .01$, or interaction, $F(2, 126) = 1.36$, $p > .37$, $\eta_p^2 = .01$ for mistakes as intersections between items. In addition, the time of execution was significantly different, $F(1,63) = 47.02$, $p < .001$, $\eta_p^2 = .32$, indicating a higher rate of execution in the paper group: paper ($M = 0.10$, $SD = 0.02$), computer ($M = 0.06$, $SD = 0.02$) . Generalising the results for the Visuospatial sketchpad task, the paper group wrote out more words at a higher rate, but this was not accompanied by a decrease in accuracy.

The Modified Bourdon test

For the Modified Bourdon test, a test of homogeneity of variance (Levene's Test) demonstrated that variances were equal ($p > .15$). According to one-way ANOVA, where the between-group factor was the type of environment, significant differences were found in the number CD, $F(1, 63) = 137.26$, $p < .001$, $\eta_p^2 = .78$ and OM, $F(1, 63) = 137.28$, $p < .001$, $\eta_p^2 = .77$ (Figure 4). No significant differences were found in the number of FA, $F(1, 63) = 0{,}04$, $p > .84$, $\eta_p^2 = .001$. The average number of CD slots in the paper group ($M = 37.6$, $SD = 5.02$) was greater than the average number of CD in the computer group ($M = 24.48$, $SD = 4.01$), and the number of OM in the paper group ($M = 6.97$, $SD = 5.03$) was less than in the computer group ($M = 20.13$, $SD = 4.04$). Additionally, the differences in execution rate were found, $F(1, 63) = 139.81$, $p < .001$, $\eta_p^2 = .68$, indicating a higher rate of execution in the paper group ($M = 0.63$, $SD = 0.17$) vs. digital one ($M = 0.41$, $SD = 0.16$). Consequently, the paper group was more accurate, missing fewer target words while completing the task at a high rate.

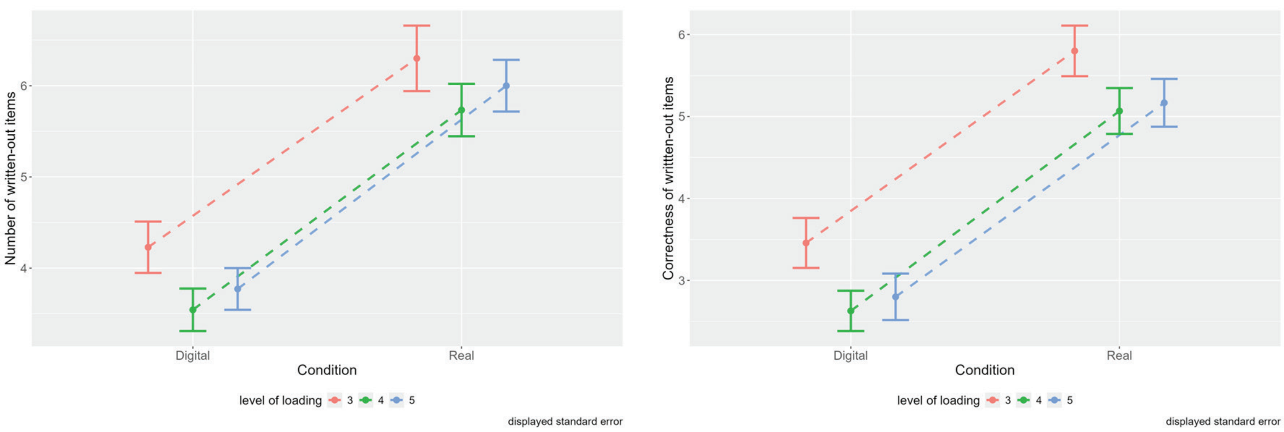


Figure 3. *Result for Visual sketchpad task in Experiment 1*

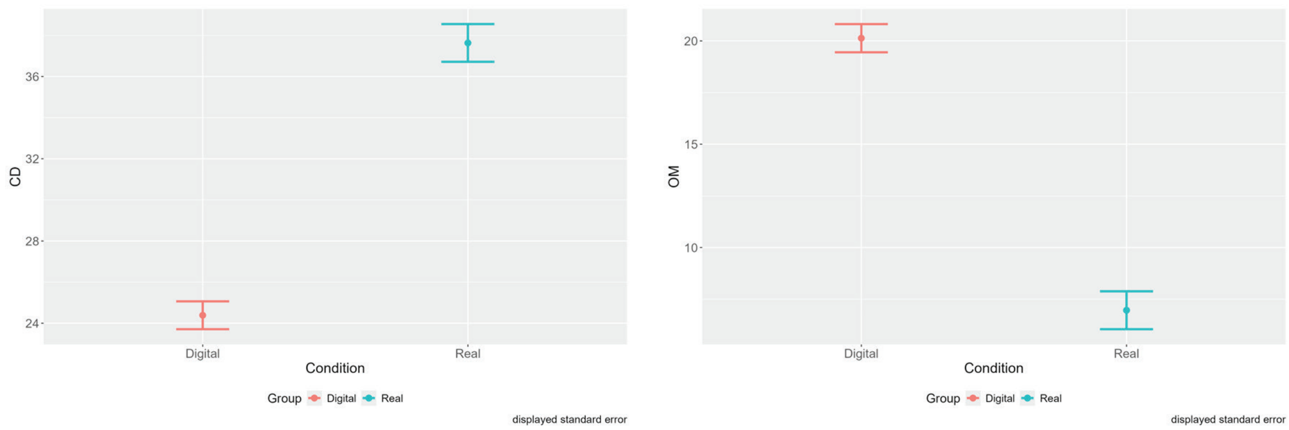


***Figure 4.** Result for Modified Bourdon test in Experiment 1*

Attentional shifting task

A test of homogeneity of variance (Levene's test) was performed for data from the Attentional shifting test; variances across all samples were equal *(*$p > .26$*)*. One-way ANOVA showed no significant differences between the number of CD, $F(1, 63) = 0.42$, $p > .52$, $\eta_p^2 = .001$, FA, $F(1, 63) = 3.53$, $p > .06$, $\eta_p^2 = .05$, and OM, $F(1, 63) = 1.23$, $p > .27$, $\eta_p^2 = .02$. Also, no differences were found in the rate of execution, $F(1, 63) = 3.01$, $p > .09$, $\eta_p^2 = .05$. Thus, no differences were found in any of the parameters.

Discussion of Experiment 1

Experiment 1 aimed at comparing attention (sustainability and shifting) and WM (visual and auditory) under real and digital conditions (paper vs. computer). No differences were found in the auditory WM task, which is consistent with the results of the study by Wiechmann et al. [2022]. This could be explained by the fact that the main differences between the environments are related to the visual dimension. This idea can be traced back to Lin et al. [Lin et al., 2015] and Umejima et al. [2021] and within our study it gained empirical ground as both auditory WM and visual-spatial WM were measured. However, mistake rates were found to increase as auditory WM load increased specifically in the digital environment. It can be assumed that when cognitive load is high, there is an influence of the type of environment. This idea is supported by the absence of the influence of the environment on the shifting. In the shifting task, subjects had to compare in one moment the information about one item (combination) with information from the search space (slots). In contrast, in the sustainability task (The Modified Bourdon test), subjects were required to search for all three items immediately to compare each slot in the search space to all items in their WM. In the latter case, the cognitive load is higher, which, together with the SAT, can lead to resource depletion in the digital environment. Thus, we can conclude that environmental influences on cognitive functions arise when cognitive load is high. Further research should aim to test this thesis. A possible methodology for organising the study could be to vary the level of cognitive load as the number of items held in WM during task performance in different environments. And measuring the level of cognitive load using appropriate tools, e.g. NASA TLX survey.

The main limitation of this experiment is the fact that the direct interaction with the medium (environment) is non-equivalent: for the real one it is a pen and for the digital one a mouse. However, according to a study by Umejima and colleagues [2021], even when the input method is equalised between paper and tablet, there are differences in speed of input and accuracy in the memory task. Which argues in favour of the fact that the differences between environments are not so much tied to instrument type and sensorimotor activity, but lie in other characteristics of the environments. Returning to the analysis of the data obtained in the present study, if the obtained superiority of the real environment was solely due to the the input method, differences would have been obtained for all four tasks. Moreover, unlike previous work where subjects entered information on different media and then reported on it (memory test), in our work in the memorisation phase, subjects did not enter it on a medium. The only thing that varied was where they saw the information — on a paper or on a screen. Consequently, the factor of the method of interaction with the environment (pen or mouse) did not influence the stage of information encoding (memorisation). It was at the report stage that the groups differed in the input method. Again, if the differences between the environments are solely related to the way information is entered, then all four tasks would show an advantage in the real environment, since both WM tasks require information to be "entered" given the retained information and both attention tasks require slots to be "crossed out". However, despite the identical input methods, the distribution of results differs, which is likely due to other factors (e.g., cognitive load, modality, visual perceptual characteristics of the environment (SAT)). To test the role of SAT in differences between environments, it is necessary to organise an empirical study in a digital environment where the input method or interaction with the medium will be identical. If its influence is present when varying in a digital environment, it can be assumed that SAT is indeed one of the environmental factors that contributes to the differences between real and digital environments.

Our study found differences in visual-spatial WM and attentional sustainability — scores were better under the real condition (paper). The results align with previous studies on memory performance [Lin et al., 2015; Umejima et al., 2021]. Thus, our study shows that attention, like memory, can be sensitive to the environment. It might be assumed that the executive/central processor plays the key role in resource allocation and is primarily associated with attention [Baddeley, 2012; Engle, 2002]. Therefore, the more sustainable attention is, the more successfully elements are held in the WM buffer. Expressed in terms of our proposed model, a saturated digital environment causes attention to be distracted by exogenous factors, which requires filtering and inhibiting information. This can lead to a depletion of attention resources, and with it WM, which reduces task performance. This view of the digital environment is also consistent with Huang's model [2003]. However, based on Norman's [1991] idea of interface's organization is designed to help the individual achieve the activity's goal. Therefore, aspects of SAT in the digital environment (perceptual feedback, notifications) can act as attention guidance factors. Due to this controversial prediction, an empirical test of the role of SAT in the digital environment is needed. Additionally, such validation is necessary as part of the developing a model that highlights SAT and its aspects as factors affecting certain cognitive functions, namely attention.

In Experiment 2 we shifted our focus on study attention (sustainability and shifting) under different digital conditions, since attention was believed to be the sensitive to the environment. Based on representations of SAT as overloading, one would expect that by removing some aspects of SAT in a digital environment would result in higher performance than in a saturated digital environment. On the other hand, if SAT is represented as guiding, then its absence in the digital environment will lead to poorer attention performance.

Experiment 2

Two competitive hypotheses were proposed. The first suggests that the digital environment, specifically its saturation (SAT), is inherently overloading. Consequently, attention will be lower in a saturated digital environment (vs. unsaturated). A competitive hypothesis is that a saturated environment contains cues that guide attention. Therefore, attention will be better in a saturated digital environment. Experiment 2.1 was aimed at studying attentional sustainability under saturated and unsaturated conditions, whereas Experiment 2.2 investigated attentional shifting.

Digital SAT was operationalized as perceptual feedback to the subject's action on website — a change in the colour or state of an interface element when it is hovered or clicked on with the mouse. It is also known as a hover effect and is the most common and basic operating principle of the interface [FreeFrontend, 2022]. A real website was created for the experiment (see Figure 5). In the saturated condition, subjects worked on a website where all elements gave a response, and the top and bottom panels were interactive (as parts of the browser and OS). An unsaturated condition was a screenshot of saturated condition which was implemented in the Psychopy programme (see Figure 5). In the unsaturated condition, subjects worked in full-screen mode, so they only saw the screen, where the top and bottom panels were part of the screen, so there was no change when hovering over any interface element. Only when they clicked on a word in the blue slot a crossed-out line appeared.

Pilot study

It was preliminarily tested whether attention differed between online and laboratory data collection. The sample consisted of 30 people, 15 of whom underwent the experiment in the laboratory in the presence of an experimenter, using standard laboratory computers, and the other 15 — who were sent a link to go through the experiment; they went through the experiment on personal computers online without the experimenter's control. The comparison of groups did not reveal significant differences in accuracy, $W = 410.5$, $p = .56$, $r = .001$. This fact allowed further data to be collected in a remote format.

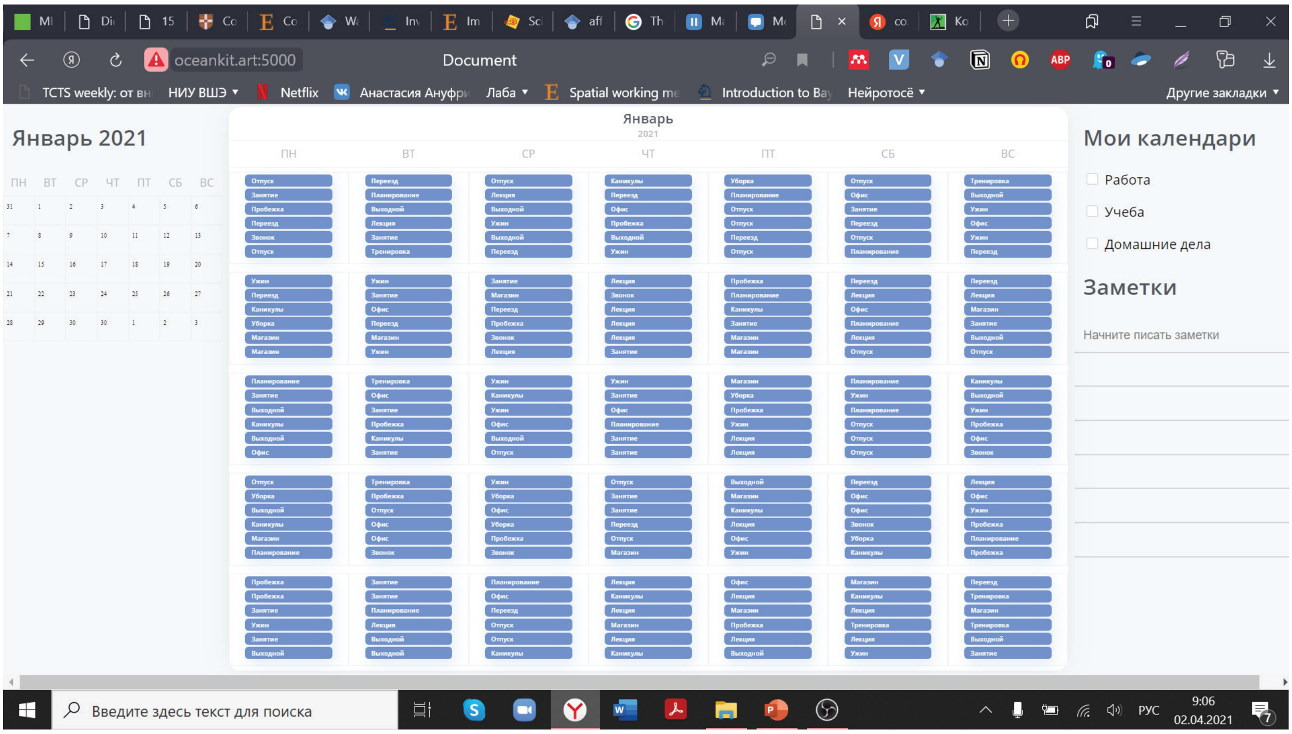


Figure 5. *The appearance of the task space for both saturated and unsaturated condition (Experiment 2.1 and 2.2)*

Experiment 2.1 Attentional Sustainability

Sample

For the experiment, 42 volunteers with normal or corrected vision who did not have neurological disorders were recruited. In academic disciplines, participation in the experiment was rewarded with a bonus point. All participants were provided with informed consent. An additional 30 people were recruited using Yandex.Toloka, where participation was rewarded with a fee of 60 rubles (about 70 cents) for a 30-minute experiment. Participants from Yandex.Toloka were selected using special filters (age range of 18-30, native Russian speakers, Russian citizenship). The exclusion criterion for them was the time and quality of task completion: if the subject completed the task in less than 25 minutes or made only three clicks in each trial, the data was excluded. The total sample included 68 subjects aged from 18 to 30 years old (M = 23.4, SD = 1.8, 30 males; 34 saturated condition, 34 unsaturated condition).

Design

SAT was a between-subject variable. Thus, there were two groups: saturated and unsaturated. There were 30 trials lasted 60 seconds each. The total number of stimuli in each trial was 210 (grid of 30 rows and 7 columns). The dependent variables were the number of correctly detected slots (CD), false alarms (FA), and rate of execution.

Procedure

Data were collected by sharing a link. The modified Burdon test was used. Participants memorized three words (for example, “training, meeting, shopping”) shown to them for 5 seconds. After that, they searched for all the slots that contained the target words for 1 minute using a mouse for response.

After completing the experiment, all subjects were asked to indicate how many tabs were open at the time of the experiment (for the unsaturated condition, subjects were relayed on the number of browser tabs on the screen), whether they were distracted by the phone or notifications, how difficult they found the task on a 5-point scale, whether they used a mouse or touchpad, whether they were used to diaries, and if so, which one (paper, electronic, or both) they preferred. This information was then used for a covariance analysis.

Results

The data were analysed using R v. 1.2.1335. The normality of the distribution was tested using the

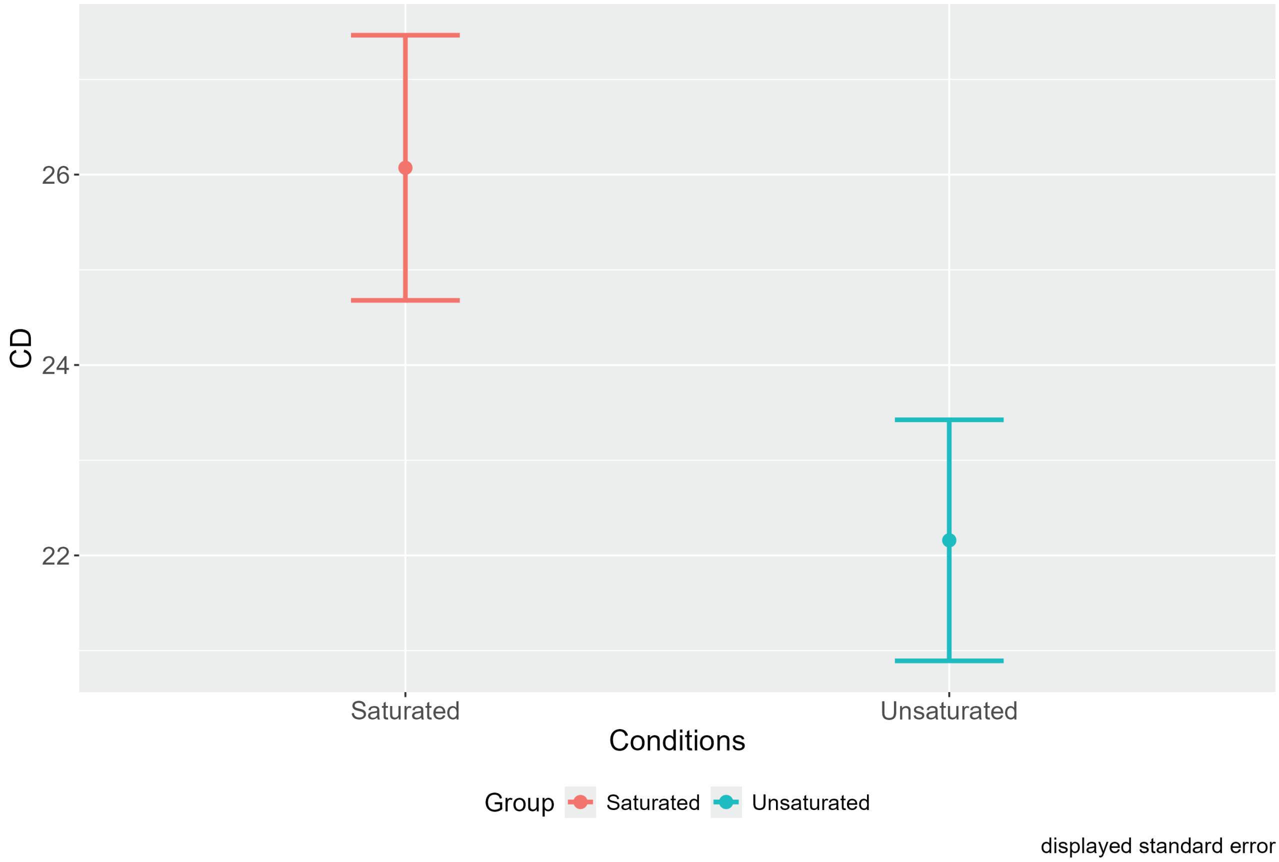


Figure 6. *Result for CD in Experiment 2.1*

Shapiro-Wilk test; the distribution was significantly different from normal ($p < .001$).

One-way ANOVA was performed with the group as the between-group factor. Levene's test confirmed homogeneity of variance between groups ($p \geq .15$). Significant effect of group, $F(1, 66) = 6.31$, $p < .01$, $\eta_p^2 = .072$, was found for CD (Figure 6. For the number of FA, there was not a significant effect of the group factor, $F(1, 66) = .02$, $p > .89$, $\eta_p^2 = .001$. An analysis of the total number of clicks revealed that under the saturated condition, an average of 26.2 clicks per 60 seconds were made, and under the unsaturated condition, an average of 22.1 clicks per 60 seconds. The differences were statistically significant, $F(1, 66) =7.8$, $p < .001$, $\eta_p^2 = .12$, indicating a higher rate of execution in the saturated condition.

Additionally, a covariance analysis was performed, where the covariates were the responses to the post-experiment survey. Results of this analysis showed no statistically significant effect of the following factors: number of tabs, experience of using a planner, preferred type of planner, subjective feeling of difficulty, and distraction ($p \geq .05$).

Experiment 2.2. Attentional Shifting

Attentional shifting was defined as a change in the search target caused by an auditory signal that resembled cell phone sound. Hypotheses and operationalisation are equivalent to Experiment 2.1.

Sample

The sample recruitment strategy and exclusion criteria are equal to Experiment 2.1. The total sample consisted of 70 subjects aged 18 to 30 years old ($M = 23.4$, $SD = 2.1$, 30 males; 36 saturated condition, 34 unsaturated condition).

Design

Experimental design is equal to Experiment 2.1

Procedure

The procedure is almost identical to that described in Experiment 2.1. Participants memorized three words demonstrated for 5 seconds. While searching, participants had to change the target by a sound that appeared every 15 seconds for 60 seconds (the sound was a 2-second beep like a telephone ring). For example, if the words "training, call, meeting" were given, subjects would first search for "training," then "call," "meeting," and then "training" again.

Results

Data analysis was performed with R v. 1.2.1335. The analysis strategy is consistent with Experiment 2.1. The normality of the distributions was tested using the Shapiro-Wilk test ($p < .04$). According to Levene's test, the variance was homogeneous ($p \geq .49$).

One-way ANOVA was performed to compare the groups. No group effect was found for CD, $F(1, 67) = .96$, $p > .33$, $\eta_p^2 = .01$. Also, there was no significant effect of group, $F(1, 66) = 2.13$, $p > .14$, $\eta_p^2 = .01$, on FA. An analysis of the total number of clicks revealed that under the unsaturated condition, an average of 19.7 clicks were performed, whereas under the saturated condition, 18.3 clicks were performed per 60 seconds. However, no significant differences were found, $F(1, 67) = 1.03$, $p > .31$, $\eta_p^2 = .01$.

Additionally, a covariance analysis was performed, in which the covariates were responses to the post-experiment survey. Results of the analysis of covariance showed no statistically significant effect of the following factors: number of tabs, experience of using the planner, preferred type of planner, subjective sense of difficulty, and fact of distraction ($p > .05$).

Discussion of Experiment 2

According to the results obtained, attentional sustainability was higher in a saturated digital environment - subjects performed the Bourdon test more accurately and faster (Experiment 2.1). However, no differences in either speed or accuracy were obtained for attentional shifting (Experiment 2.2). These results for both attentional properties are consistent with Experiment 1, suggesting an advantage of the saturated condition over the unsaturated condition. Thus, SAT expressed in such an aspect as perceptual feedback (hover effect) can be seen as guiding attention rather than overloading it. This raises a paradox: SAT of the digital environment overloads attention relative to the real environment, but excluding SAT from the digital environment results in worse attention performance relative to the digital environment with SAT.

General Discussion

In the present study, the advantage of the real environment over the digital environment was obtained in the context of visuo-spatial WM and attentional sustainability (Experiment 1). Auditory WM was found to be insensitive to variation in the environment. Thus, the results are consistent with the ideas from previous studies — it is in the visual modality that the perceived differences between environments, and hence the influencing factors, lie. In addition, no differences were found in attentional shifting, which may be due to the low level of cognitive load compared to the sustainability attention task (see, Discussion of Experiment 1). This suggests a potential interaction between environmental influences and the level of cognitive load induced by the task itself and may form the basis for further research.

This study is the first to show for the first time the sensitivity of attentional sustainability to the environment using a modification of the classical methodology, thus expanding our understanding of possible mechanisms of environmental influences. In particular, we presented our own attempts to formulate a theoretical model, as there is currently no well-established system of ideas about the factors of environmental influences on cognitive functions in the field of CDI. Our model suggests that environments differ primarily in the degree of saturation (SAT) that influences retention, redirection, and monitoring by attention. The digital environment has a high SAT compared to the real one. One aspect of SAT is perceptual feedback, aka hover effect. This aspect can be called the most basic aspect that distinguishes between real and digital environments. Based on the results of Experiment 1, we hypothesised that it is the saturation of the environment, and in particular the presence or absence of the hover effect, which may underlie the overloading effect of gadgets. To test this idea, Experiment 2 was conducted. Based on the idea that the presence of the hover effect as an aspect of SAT affects attention in an overloading way, it was expected to see improved performance in a situation of absence in a digital environment (website). However, our model takes into account Activity-centered design's notion that interface elements are designed to help the individual achieve the goal of the activity. Hence, excluding the hover effect may negatively affect attention performance. Based on the results of Experiment 2, we obtained a superiority of the saturated environment over the unsaturated environment, suggesting a guiding influence of the hover effect in the digital environment. Comparing the results of the two experiments, we can say that SAT can affect attention performance, and with it WM, as the two constructs are closely related [Scott, 2010]. However, a paradox of the directionality of influence is observed.

Given the ambiguity of SAT effects, we can assume that the environment effect does not depend solely on this characteristic and its aspects. Combination with other factors may lead to such an outcome. One of them can be the degrees of freedom (DF), which was introduced in the description of our model. However, since the feature or its availability was not varied within the given experiments, it is not possible to properly analyse and speculate on the nature of the DF and SAT interaction. Further work within the study of environmental influences should also aim to elaborate on the operationalisation and variation of both SAT and DF together. Turning to data from other studies, it is possible to try to highlight factors that are thought to influence the resulting pattern of data. For example, the possibility of cognitive offloading through sensorimotor activity due to differences in the tools used to interact directly with the environments. Specifically, the unified action hypothesis suggests that coordination of eyes and hand movements wastes less cognitive resources [Mangen et al., 2013; Risko & Gilbert, 2016]. Thus, in a real environment, the degree of coordination is higher because the eyes and hands are at the same point when performing an action. Also, there is a role for spatial features that are available in reality, for example, remoteness and depth [Snow et al., 2014]. Finally, environments are characterised by the need for navigation, which can be understood both as a feature of the organisation of actions to realise the functions of the environment, involving sensorimotor factors, and the construction of a mental spatial map of the environment, which can be related to the availability of information for stabilisation and appropriate coding [Lin et al., 2015; Hou et al., 2017]. Consequently, we can assume that in the real environment the representation of information is more stable and richer, which favours its retention and encoding, and the variant of sensorimotor interaction with it allows spending less resources on coordination of actions. Moreover, it does not involve special navigation, which also saves resources. In the case of the digital environment, however, eye-hand coordination requires more resources and there is an abundance of information that can act as exogenous factors that expend the resource of attention to filter and suppress them. Also, the digital environment implies a relatively complex navigation system to interact with it. This is where the differences between real and digital environments come from. However, a number of exogenous factors, such as the hover effect, can act as signifiers that are designed to facilitate navigation in the digital environment by directing attention to functional elements [Norman, 2008]. Their presence does not equalise task performance in digital and real-world environments, but in their absence in digital environments they can significantly impede attention performance. Thus, further research should focus on uncovering the interaction of the SAT aspects and their functional roles within digital environment. In particular, it is possible to replicate Experiment 2 using an eye-tracker to capture the character of the search space scanning. This will make it possible to clarify the nature of the hover effect influence on the overt attention.

Conclusion

The present study presented the results of comparing working memory and attention in real and digital environments using modifications of classical methods. In particular, for the first time the sustainability and shifting of attention, as well as auditory working memory were tested. In addition, the present paper presented the first attempt to formulate a theoretical model of environmental influences on cognitive functions. The main finding of this empirical study is that the digital environment is not exclusively overloading. Some aspects of it can act as a cueing system that facilitates the activity of attention. The proposed theoretical model and the results of empirical tests may form the basis for further systematic research on the effects of the digital environment on cognitive functions.

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Перегружает, но направляет: влияние средовой насыщенности на внимание и рабочую память в реальных и цифровых условиях

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Цифровая среда окружает нас повсюду. Однако мало что известно о различиях между влиянием цифровой и реальной среды на когнитивные функции. Изначально целью настоящего исследования было сопоставление показателей внимания и рабочей памяти (РП) в цифровых и реальных условиях. В Эксперименте 1 внимание и РП оценивались с помощью модифицированных версий классических заданий, представленных в цифровом (на компьютере) или реальном (на бумаге) формате. Результаты показали, что устойчивость внимания и зрительная РП были выше в реальной среде, что говорит о потенциальном перегружающем эффекте цифрового условия. В Эксперименте 2 изучались механизмы, лежащие в основе переключаемости и устойчивости внимания в цифровой среде, с помощью варьирования насыщенности цифровой среды. (SAT). SAT отражает степень интерактивности среды, в частности, инициируются ли действия и направляются человеком или системой (например, элементами интерфейса). SAT была операционализирована как перцептивная обратная связь - эффект наведения (изменения состояния или цвета элементов в ответ на действия пользователя). Результаты показали, что показатели устойчивости внимания были выше в цифровой среде с высокой SAT, в то время как для переключаемости внимания этот эффект не наблюдался. Эти результаты свидетельствуют о том, что, хотя цифровая среда может перегружать внимание по сравнению с реальной, определенные характеристики насыщенности — например, интерактивная обратная связь – могут облегчать работу внимания. Таким образом, насыщенность среды играет определяющую роль в протекании когнитивных процессов.

Ключевые слова: цифровая и реальная среды, когнитивно-цифровое взаимодействие, рабочая память, внимание, эффект наведения, перегрузка, направление

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